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Emissions from a Light-Duty Diesel: Ambient Temperature and Fuel Effects

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ABSTRACT

Exhaust emissions from a diesel passenger car were characterized and measured to examine the effect of ambient temperature on emissions performance. The vehicle was tested at three temperatures on a chassis dynamometer located within a cold cell. Three driving cycles and three fuels of varying quality were used. The effort included measurements of regulated exhaust gases and particles, particulate organic fractions and their molecular-weight distributions, particulate fractions under 2 microns in diameter, trace metal contents, and fuel economy. Results indicate that reductions in ambient temperature had little effect on emissions or fuel economy in this study. In some cases, statistically significant increases in NO_x emissions were measured with decreases in ambient test temperature. Other differences related to temperature effects occurred more frequently with the lower quality fuels.

UNDER SECTION 202 PART A OF THE CLEAN AIR ACT, the Administrator of the Environmental Protection Agency (EPA) is required by law to establish standards regulating emissions from new motor vehicles. In carrying out this mandate, emissions from motor vehicles are examined under a variety of driving conditions, ambient temperatures, and transient or steady-state speeds. Effects related to the use of different fuels are also examined. Emission factors obtained in these studies enable prediction of the impact of specific pollutants on the public health.

Pursuant to the need for obtaining additional emission factor information, the central thrust of this study was directed at an examination of the sensitivity of light-duty diesel emissions to ambient temperature. Because previous temperature studies (1-4)* had left the fuel and driving cycle parameters unexplored, an additional objective was to investigate temperature sensitivity by including these parameters.

Results obtained in the low temperature studies cited above have led to the general conclusion that regulated gas emissions, including hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x), are not nearly so temperature dependent as those from conventional spark-ignition engines. Particulate matter emissions appear more sensitive to temperature; however, their precise trends are not well understood. For example, in experiments run by Braddock (3) in which the temperature of the cold soak (pretest conditioning), exhaust dilution air, and test run approximated local winter ambient conditions, particulate emission rates increased with decreasing temperatures. The opposite trend was noted in tests by Seizinger et al. (4)

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*Numbers in parentheses designate references at end of paper.

in which cold soak and run temperatures were maintained at near constant preset levels and room air (70°F) was used to dilute exhaust gases for sampling.

In this study the vehicle was soaked and run in a temperature-controlled cell similar to that used by Seizinger. Therefore, temperatures could be set and closely controlled to near constant levels throughout the cold soak and emissions test. Exhaust gases were diluted in room air maintained around 72°F.

The emissions characterization included regulated diesel automobile pollutants HC, CO, NO_x, and particulate matter, particulate soluble organic fractions (SOF), particulate fraction under 2μ mass median diameter (MMD), SOF molecular weight distributions, and particulate elemental emissions. Samples have also been collected for determination of SOF polynuclear aromatic hydrocarbon content and Ames bioassay activity. However, results are not available for inclusion in this paper.

EXPERIMENTAL PROCEDURE

VEHICLE SELECTION--Resource limitations permitted examination of only one vehicle. The selected car, a 1984 Oldsmobile 98 Regency, was equipped with a 5.7-l, V-8 diesel engine. A more complete description of the vehicle is given in Table 1.

The Oldsmobile was a consumer-owned vehicle loaned to EPA for the duration of the study. It was selected from a group of vehicles owned by Raleigh, N.C., residents who had been solicited for participation in the diesel emissions project. Selection of the Oldsmobile was predicated on the desire to test a large, rear wheel-drive vehicle because such vehicles generally display better run-to-run repeatability on a chassis dynamometer. Both gaseous and particulate matter emission rates were found to be highly repeatable.

TEST FUELS--Three fuels were examined in the study: (1) "baseline", (2) "high quality", and (3) "low quality" (see Table 2). Both the low quality and high quality fuels were specially blended diesel fuels provided by the Coordinating Research Council, Inc. (CRC) following their use in the CAPE-32-80 project at the Southwest Research Institute (5). The high quality fuel was characterized by high cetane number and low aromatic content; the low quality fuel by low cetane number and high aromatic content. The boiling ranges of both fuels were intentionally similar. Because only small quantities of these fuels were available, testing at low temperatures was limited to the Urban Dynamometer Driving Schedule (UDDS).

The baseline fuel was a No. 2 diesel fuel obtained from a local vendor. It was used in preliminary tests to qualify sampling and analysis systems and temperature effects for a variety of transient cycles. It was the only fuel for which emissions data were obtained at each of the three temperatures and test cycles examined.

TEST PROCEDURES

DRIVING CYCLES--Most of the tests were conducted using the EPA's UDDS, which is divided into three phases: cold transient (Phase 1), stabilized (Phase 2), and hot transient (Phase 3). A 10-min soak interval is included between the stabilized and hot transient phases, during which time no exhaust emissions are generated.

Tests were also run using the highway fuel economy test (HFET) and the New York City cycle (NYCC). The HFET is the driving cycle used to determine highway fuel economy ratings (6,7), and the NYCC is used to simulate slow, stop-and-go city driving. Descriptions of all test cycles conducted in this study are given in Table 3.

FACILITY DESCRIPTION--All emission tests were conducted with a chassis dynamometer for vehicle road load simulation. The dynamometer simulated road load by means of a DC electric motor-generator directly coupled to the front rolls of the dynamometer. The rear rolls were coupled during tests to the front rolls through engagement of a clutch located on the front shaft.

Exhaust gases from the test vehicle were directed via a 7.6-cm (3-in.) diameter, flexible, stainless steel line to a 20.3-cm (8-in.) diameter dilution tunnel (Figure 1). Within the tunnel, raw exhaust gas was thoroughly mixed with filtered dilution air, and the diluted mixture was then drawn through the system by a positive displacement pump located downstream. Temperature of the diluted gas varied slightly but was generally around 100°F; flow rates within the constant volume system (CVS) were maintained at 620 scfm. Gas and particulate matter samples were collected using probes inserted in the diluted exhaust gas within the tunnel.

Low temperatures were simulated using a refrigerated cell that enclosed the vehicle on the dynamometer. Test temperatures were held constant in the cell during the test and during the cold soak period immediately before it. Temperatures were monitored using thermocouples located in the engine's crankcase oil and coolant and in the cold cell.

Before each UDDS, the vehicle was conditioned (soaked) at the test temperature for 8 h. After warming up the dynamometer, the vehicle was pushed onto the dynamometer rolls and testing proceeded.

During the UDDS and NYCC, temperatures inside the test cell hovered within two degrees of the temperature set point. The largest temperature deviation (+7°F) occurred during HFETs at the 20°F set point. Temperatures monitored in the engine's oil sump are plotted as a function of test time in Figure 2 for each of the test cycles and test temperatures examined. These graphs indicate that ambient temperature has its greatest influence on engine and oil temperature at the beginning of each test and that it continues to influence temperatures even after the engine is fully warmed up. This finding is contrary to results reported by Braddock (3), probably because tests in this study were conducted in a temperature-controlled cold cell.

The testing sequence and the sampling effort summary is shown in Table 4. The vehicle was first tested using the baseline fuel to identify conditions that were sensitive to ambient temperature changes. Because HFET and NYCC emissions did not appear to be affected by low temperature operation, these cycles were excluded from the 20°F and 50°F tests with the low and high quality fuels.

GASEOUS AND PARTICULATE EMISSIONS METHODS--Emissions of HC, CO, CO_2, NO_x, and total particulate mass were measured according to Federal Register procedures. Conventional hot flame ionization detection procedures were used for HCs, nondispersive infrared procedures for CO and CO_2, and chemiluminescence procedures for NO_x. Total particulate emission rates were measured by sampling the diluted exhaust flow with four parallel 20 x 20-in filters (8). Individual test phase and composite FTP particulate emission rates were measured with 47-mm filters (9). Particulate SOF was determined using previously described filtration-gravimetric and solvent-extraction procedures (10). The fractions of particles with less than 2μ MMD (2μ cutoff) were determined using a cyclone size-selective sampling procedure of John and Reischl (11). Pallflex T60A20 Teflon-coated glass fiber filters were used for all particulate filtration, with the exception that Fluoropore FA Teflon membrane filters were used to collect particles for elemental analysis by x-ray fluorescence (12). Molecular weight distributions of the particulate organics in the C_{12} to C_{38} range were determined by gas chromatography according to the procedure of Black and High (10).

RESULTS AND DISCUSSION

REGULATED AND PARTICULATE SOF EMISSIONS AND FUEL ECONOMY TRENDS--Averages and standard deviations of the test results for the emissions of HC, CO, NO_x, particulate matter, and SOF and for fuel economy are presented for each of the three test temperatures in Tables 5 and 6. In general, emissions differences due to temperature changes are small. Statistically significant differences that do occur are most frequent with the low quality fuel and least frequent

with the high quality fuel.

For the baseline and low quality fuels, UDDS Phase I HC emissions are higher at the 20°F temperature. Such elevated levels are reasonable to expect during this cold start portion when unburned HCs are more readily quenched on cold cylinder surfaces. However, for the HFET and NYCC, HC emissions are actually lower at the 20°F test. Since both are warm-start tests, cold quenching is reduced and an increase in engine volumetric efficiency due to the intake of cooler, more densely packed charges of air, becomes the controlling mechanism in reducing HC emissions. Increases in volumetric efficiency also affect CO emissions, which show a slight tendency to decrease with cooler temperatures in a warmed-up engine, particularly with the low quality fuel (see Table 5). Increased NO_x emissions with decreases in test temperature were the most consistent and significant temperature effects noted. These trends were observed with all fuels and test cycles examined. For the UDDS, NO_x emissions increased an average of 33 percent from the 75°F to the 20°F test temperature. These increases largely resulted from increased engine load at low temperatures due to greater friction losses in the engine, drivetrain, and tires. Fuel economy trends, which reflect engine loading, also fell slightly with a decrease in temperature. An average drop of 9% was observed in the UDDS when the temperature was reduced from 75°F to 20°F. Significant drops in fuel economy with decreased temperatures can be seen in the UDDS Phase I data which best reflect cold-start and warm-up conditions. Emission of particulate matter decreases slightly with lowered temperature when using low quality fuel. Otherwise, particulate matter and SOF do not appear to be significantly affected by temperature in this study. Since gas phase adsorption is a temperature-dependent process, this observation could be biased by not using cold dilution air.

with the high quality fuel.

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Emission differences due solely to fuel effects are apparent in Tables 5 and 6. Differences in HC, CO, and SOF emissions are significant, while those for NO_x and particulate matter are not. The Urban Dynamometer Driving Schedule HC emissions with the low quality fuel were about four times higher than those with the high quality fuel. Comparable differences were also observed in HFET and NYCC tests. This tendency for large increases in HCs with increase in fuel aromatic content was also observed in the CRC, CAPE 32-80 project (5). Test results in that project with a 1982 Oldsmobile operating on the same low and high quality fuels indicated a five fold increase in HCs with the low quality fuel. Carbon monoxide emissions were also sensitive to fuel type but emission differences were not so pronounced as those noted with HCs. For the UDDS, CO increased about 40% when operating on the low quality fuel. Particulate matter emissions were not significantly affected by fuel type, but particulate SOF (extractables) was substantially lower for the high quality fuel.

A comparison of emission rates and trends observed in this study with those observed in the CRC study mentioned previously is shown in Figure 3. Both studies contain an examination of identical high and low quality fuels, but the CRC data are for a 1982 Oldsmobile. In general, comparison between fuel effect trends in both studies is good. Hydrocarbons, CO, and SOF increase with use of the low quality fuel; total particulate matter mass emissions remain almost unchanged.

TRACE ELEMENT, MOLECULAR WEIGHT DISTRIBUTION, AND PARTICULATE SIZE TRENDS--Particulate matter emissions were examined for trace element content using an x-ray fluorescence technique. Results from these examinations are given in Table 7. Values represent content as a percent of the total trace element content. Trace elements comprised about 3% of the total particle

weight, which is in close agreement with results in other studies (14, 15). Neither fuel nor test temperature appears to have any effect on particulate trace element content in this study.

The molecular weight distribution of the particulate organic extract was examined for shifts due to temperature effects with the low quality and high quality fuels. Results graphically depicted in Figure 4 illustrate that shifts in the distribution fail to occur in the UDDS regardless of temperature or fuel effects. The median carbon number of the molecular weight distribution histograms, which is defined as the carbon number value equally dividing the total area of the bars, is approximately C_{22} at all temperatures for both fuels. Results contrary to these reported in a previous study (3) indicate a pronounced shift occurring toward lower molecular weight compounds at low ambient temperature. Because dilution air for the exhaust gas sampling system was at ambient temperature in that study, the shift at low ambient temperature might be attributed to phenomena associated with low temperature gas phase adsorption of low molecular weight organic compounds.

The effect of ambient temperature and fuel usage on the fraction of particles less than 2μ in diameter is shown in Figure 5. Considering the magnitude of the standard deviations depicted, neither ambient temperature nor fuel usage appear to have any significant effect on the 2μ fraction. Again it should be pointed out that the exhaust particles were being transported in diluted exhaust at roughly 100°F before collection and analysis. Therefore, the fate of the particles after tailpipe exit would likely be different in a

real-world situation in which they would be immediately subjected to low ambient temperatures.

SUMMARY AND CONCLUSIONS

Sensitivity of exhaust emissions to ambient temperature was examined from a 1984 Oldsmobile Regency Diesel while varying fuel and driving cycle parameters. Testing at ambient temperatures of 75°F, 50°F, and 20°F generally had little effect on emissions and fuel economy for any of the fuels and driving cycles examined. However, effects noted occurred more frequently and to a greater extent with the lower quality fuels. Sensitivity to temperature was also most apparent during Phase I of the UDDS, which represents the cold-start and warm-up phase of engine operation. Hydrocarbon and CO emissions tended to increase with decrease in ambient temperature during Phase I, while the opposite trend, if any, was observed for cycles representing hot-start or warmed-up engine operating conditions.

Conclusions specific to the Oldsmobile tested in this study are follow:

1. Increase in NO_x emission with decrease in ambient temperature was the only consistently significant temperature effect observed.
2. Hydrocarbon and CO emissions increased at low temperature during the cold-start Phase I of the UDDS with lower quality fuels, but they showed either no change or decreases for other test phases and cycles simulating warmed-up engine operation.
3. Particulate matter emission rates decreased slightly at low temperature with the low quality fuel.
4. Decreases in fuel economy at low ambient temperature, though not significant in the HFET and NYCC, were apparent in Phase I of the UDDS's.

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Table 1. Vehicle Description

Type	Oldsmobile 98 Diesel
Model year	1984
Vehicle size	Full-size
Number of doors	4
Passenger capacity	6
Odometer (miles)	18,000
Number of cylinders	8
Displacement, CID(l)	350 (5.7)
Transmission type	Automatic 3-spd
Test inertia (lbs)	4500
50 mph road load (HP)	10.8
Emission controls	EGR

Table 2. Fuel Description

	Baseline	High Quality	Low Quality
Aromatic Volume(%)	-	24.0	51.8
Cetane No.	42.1	46.8	32.0
10% BP (°F)	428	375	378
50% BP (°F)	509	456	463
90% BP (°F)	597	535	537
Flash Point (TCC)	161°F	133°F	139°F
API Gravity (60°F)	33.9	41.6	33.4
Viscosity (CST~100°F)	2.71	1.80	1.73

Table 3. Test Cycle Description

Test Cycle	Cold Start	Avg. Speed	Stops per mile	Total Distance (mile)	Duration (minute)	Percent idle
UDDS	Yes	21.3	2.40	11.1	31.3	19.0
Phase 1	Yes	25.7	1.70	3.6	8.4	10.6
Phase 2	No	16.2	3.08	3.9	14.5	18.0
Phase 3	No	25.7	1.70	3.6	8.4	20.6
HFET	No	48.2	0.20	10.2	12.7	0.8
NYCC	No	7.1	9.32	1.2	10.0	40.2

Table 4. Test Sequence and Sampling Effort

	Activity	Data Acquisition Effort *
I. Baseline Fuel		
A. 75°F Tests	UDDS	A,B,C,D,E,
	Phase I	A,B
	Phase II	A,B
	Phase III	A,B
	HFET	A,B,E
	NYCC	A,B,E
B. 50°F Test	Same as A.	
C. 20°F Test	Same as A.	
II. Low and High Quality Fuels		
A. 75°F Tests	Same as I.A.	
B. 50°F Tests	UDDS	A,B,C,D,E
	Phase I	A,B
	Phase II	A,B
	Phase III	A,B
C. 20°F Tests	Same as II.B.	

*Key:
A- Regulated emissions
B- 47mm Pallflex filters
C- 20-x20-in. filters
D- 47-mm Teflon filters
E- 2μ Cyclone

Table 5. Regulated Exhaust Gas Emission Trends

	BASE FUEL			LOW QUALITY FUEL			HIGH QUALITY FUEL		
	75°F	50°F	20°F	75°F	50°F	20°F	75°F	50°F	20°F
HC EMISSIONS (g/mi)									
UDDS	0.15 ± .02	0.15 ± .00	0.15 ± .01	0.29 ± .04	0.20 ± .02	0.24 ± .06	0.07 ± .01	0.07 ± .01	0.08 ± .01
Phase 1	0.20 ± .02	0.21 ± .02	0.25 ± .00	0.49 ± .10	0.47 ± .07	0.67 ± .03	0.09 ± .01	0.08 1 .02	0.09 ± .01
Phase 2	0.13 ± .02	0.14 ± .01	0.13 ± .01	0.21 ± .03	0.12 ± .01	0.12 ± .01	0.07 ± .01	0.06 ± .01	0.07 ± .01
Phase 3	0.13 ± .02	0.14 ± .01	0.12 ± .01	0.28 ± .03	0.16 ± .01	0.16 ± .03	0.08 ± .01	0.06 ± .01	0.07 ± .01
HFET	0.07 ± .01	0.06 ± .01	0.05 ± .01	0.12 ± .01	-	-	0.04 ± .01	-	-
NYCC	0.37 ± .02	0.35 ± .03	0.25 ± .05	0.58 ± .08	-	-	0.15 ±.04	-	-
CO EMISSIONS (g/mi)									
UDDS	0.78 ± .04	0.80 ± .03	0.85 ± .04	0.99 ± .04	0.88 ± .01	0.90 ± .03	0.70 ± .03	0.70 ± .04	0.69 ± .01
Phase 1	0.80 ± .05	0.86 ± .11	1.08 ± .09	1.06 ± .10	0.98 ± .03	1.02 ± .06	0.72 ± .03	0.73 ± .04	0.76 ± .05
Phase 2	0.78 ± .02	0.83 ± .04	0.82 ± .03	0.97 ± .03	0.87 ±.02	0.90 ± .04	0.72 ± .05	0.73 ± .05	0.69 ± .02
Phase 3	0.70 ± .06	0.72 ± .06	0.72 ± .05	0.98 ± .08	0.83 ± .01	0.82 ± .02	0.66 ± .02	0.64 ± .02	0.62 ± .02
HFET	0.41 ± .02	0.42 ± .03	0.41 ± .03	0.51 ± .03	-	-	0.40 ± .01	-	-
NYCC	1.71 ± .08	1.69 ± .10	1.61 ± .02	2.07 ± .07	-	-	1.32 ± .01	-	-
NOx EMISSIONS (g/mi)									
UDDS	1.84 ± .02	2.24 ± .04	2.41 ± .17	1.83 ± .32	2.14 ± .08	2.62 ± .03	1.86 ± .05	1.95 ± .02	2.35 ± .15
Phase 1	1.55 ± .07	1.98 ± .15	2.12 ± .17	1.66 ± .06	2.01 ± .05	2.47 ± .05	1.62 ± .07	1.80 ± .07	2.11 ± .11
Phase 2	2.07 ± .05	2.55 ± .04	2.71 ± .21	1.93 ± .37	2.35 ± .13	2.93 ± .05	2.06 ± .06	2.20 ± .01	2.68 ± .18
Phase 3	1.65 ± .08	1.82 ± .18	2.04 ± .16	1.77 ± .47	1.82 ± .05	2.14 ± .04	1.65 ± .03	1.70 ± .05	1.90 ± .14
HFET	1.11 ± .04	1.32 ± .17	1.32 ± .14	1.04 ± .15	-	-	1.09 ± .04±	-	-
NYCC	3.76 ± .20	4.57 ± .57	4.51 ± .47	3.68 ± .46	-	-	3.78 ± .16	-	-

Table 6. Trends for Particulate Emissions and Fuel Economy

	BASE FUEL			LOW QUALITY FUEL			HIGH QUALITY FUEL		
	75°F	50°F	20°F	75°F	50°F	20°F	75°F	50°F	20°F
PARTICULATE MATTER EMISSIONS (g/mi)									
UDDS	0.32 ± .04	0.36 ± .01	0.35 ± .02	0.32 ± .03	0.27 ± .03	0.26 ± .01	0.27 ± .06	0.35 ± .13	0.27 ± .01
Phase 1	0.47 ± .09	0.57 ± .04	0.56 ± .09	0.45 ± .10	0.40 ± .04	0.41 ± .04	0.31 ± .16	0.45 ± .14	0.39 ± .03
Phase 2	0.29 ± .02	0.30 ± .01	0.30 ± .02	0.29 ± .01	0.24 ± .02	0.22 ± .02	0.26 ± .03	0.31 ± .11	0.24 ± .01
Phase 3	0.26 ± .06	0.32 ± .00	0.35 ± .08	0.28 ± .03	0.24 ± .02	0.21 ± .04	0.25 ± .04	0.33 ± .16	0.25 ± .01
HFET	0.17 ± .01	0.19 ± .03	0.18 ± .02	0.18 ± .01	-	-	0.16 ± .02	-	-
NYCC	0.51 ± .04	0.66 ± .20	0.66 ± .19	0.46 ± .04	-	-	0.41 ± .02	-	-
PARTICULATE SOF (%)									
UDDS	21.5 ± 2.7	18.5 ± 2.6	17.8 ± 2.0	20.9 ± 2.1	18.7 ± 1.5	22.2 ± 2.8	14.4 ± 2.1	16.9 ± 5.2	13.8 ± 0.6
Phase 1	18.5 ± 2.1	16.2 ± 2.1	16.5 ± 3.5	19.5 ± 1.9	18.9 ± .07	20.9 ± 4.9	14.1 ± 7.3	16.5 ± 7.7	10.1 ± 0.6
Phase 2	21.4 ± 4.0	17.2 ± 3.0	16.5 ± 1.6	17.9 ± 2.4	16.2 ± 2.5	19.6 ± 2.5	13.1 ± 1.8	18.9 ± 10.7	13.6 ± 1.5
Phase 3	25.6 ± 3.5	24.0 ± 3.3	21.5 ± 2.9	27.2 ± 2.8	23.2 ± 1.5	30.6 ± 9.2	19.1 ± 2.2	15.0 ± 6.1	18.4 ± 0.1
HFET	32.0 ± 2.2	29.2 ± 9.5	-	30.5 ± 3.2	-	-	24.0 ± 2.6	-	-
NYCC	19.6 ± 3.5	22.7 ± 7.2	-	16.0 ± 2.0	-	-	11.4 ± 2.8	-	-
FUEL ECONOMY (MPG)									
UDDS	22.6 ± 0.8	21.4 ± 1.3	20.0 ± 0.6	21.5 ± 0.7	22.0 ± 0.8	20.8 ± 0.7	22.5 ± 0.5	21.5 ± 0.6	20.6 ± 1.4
Phase 1	23.2 ± 0.7	20.4 ± 1.2	17.4 ± 0.8	21.3 ± 0.4	20.9 ± 0.5	18.9 ± 1.2	21.7 ± 0.8	19.9 ± 0.8	19.8 ± 0.6
Phase 2	22.3 ± 0.8	20.6 ± 0.5	20.8 ± 1.8	22.1 ± 0.8	22.1 ± 1.2	20.9 ± 0.9	22.2 ± 0.5	21.5 ± 1.0	20.0 ± 2.2
Phase 3	23.0 ± 2.1	24.6 ± 4.3	20.9 ± 1.4	20.8 ± 1.3	22.8 ± 0.6	22.3 ± 0.8	23.8 ± 0.9	23.1 ± 1.0	23.0 ± 0.5
HFET	35.5 ± 0.9	34.6 ± 0.6	34.2 ± 2.4	34.8 ± .07	-	-	35.2 ± 0.7	-	-
NYCC	12.1 ± 0.4	11.8 ± 0.2	11.4 ± 0.9	11.5 ± 0.4	-	-	12.4 ± 0.8	-	-

Table 7. Elemental Analyses Results

Fuel	Test Temp. (°F)	Al	P	S	Ca	Fe	Cu	Zn
Low Quality	20	0.9	2.0	64.5	1.5	26.0	1.4	3.8
	50	1.1	1.9	65.2	1.5	26.3	0.8	3.0
	75	0.9	2.1	67.1	1.7	22.2	1.4	4.4
High Quality	20	1.4	1.9	58.0	1.6	29.7	1.3	4.4
	50	1.1	2.1	62.8	1.7	27.0	1.3	4.4
	75	1.1	2.0	61.5	1.8	27.5	1.4	3.8

Figure 1

AUTO EXHAUST SAMPLING SCHEME

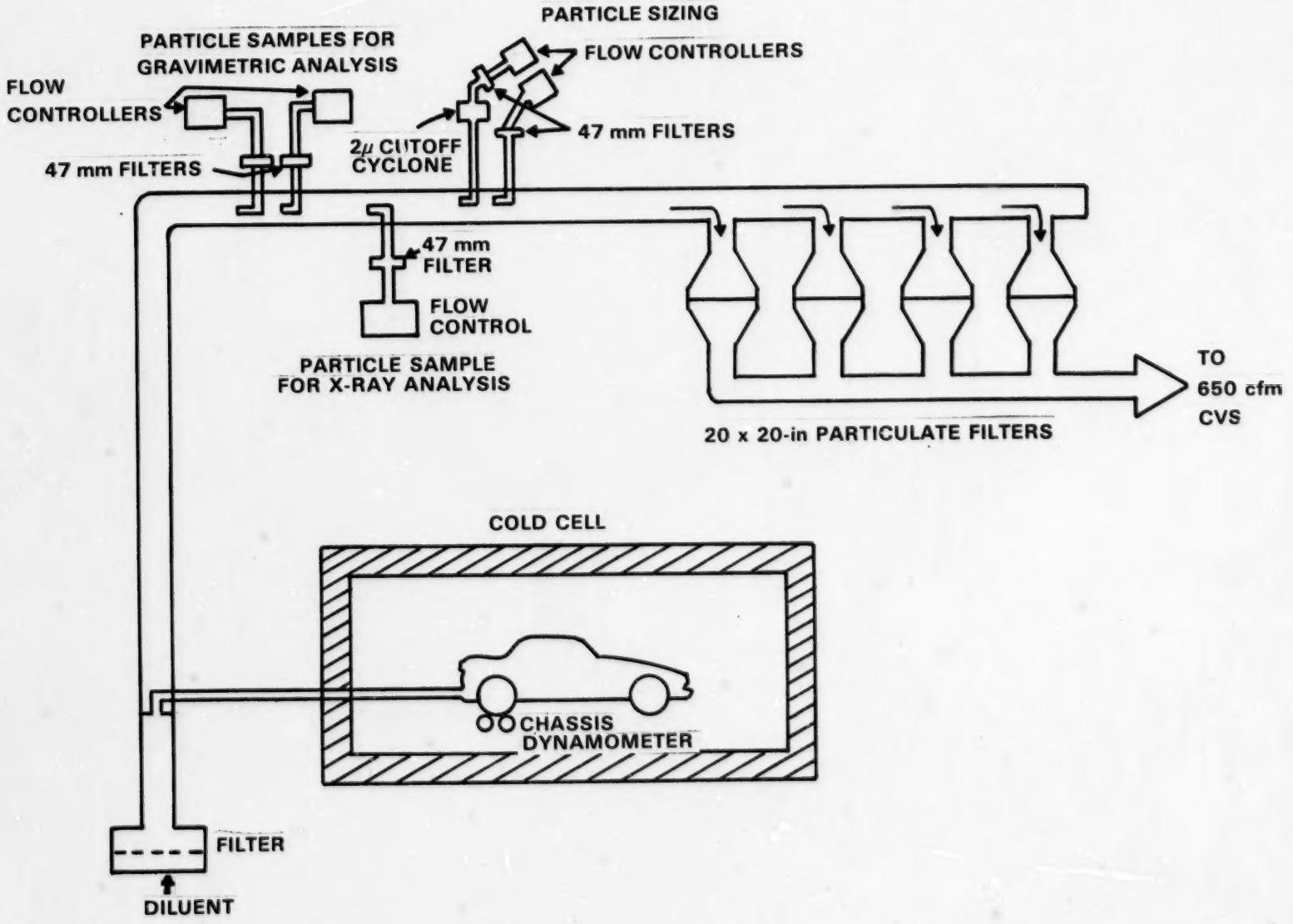

Figure 2a. Oil Sump Temperature vs. Time For UDDS

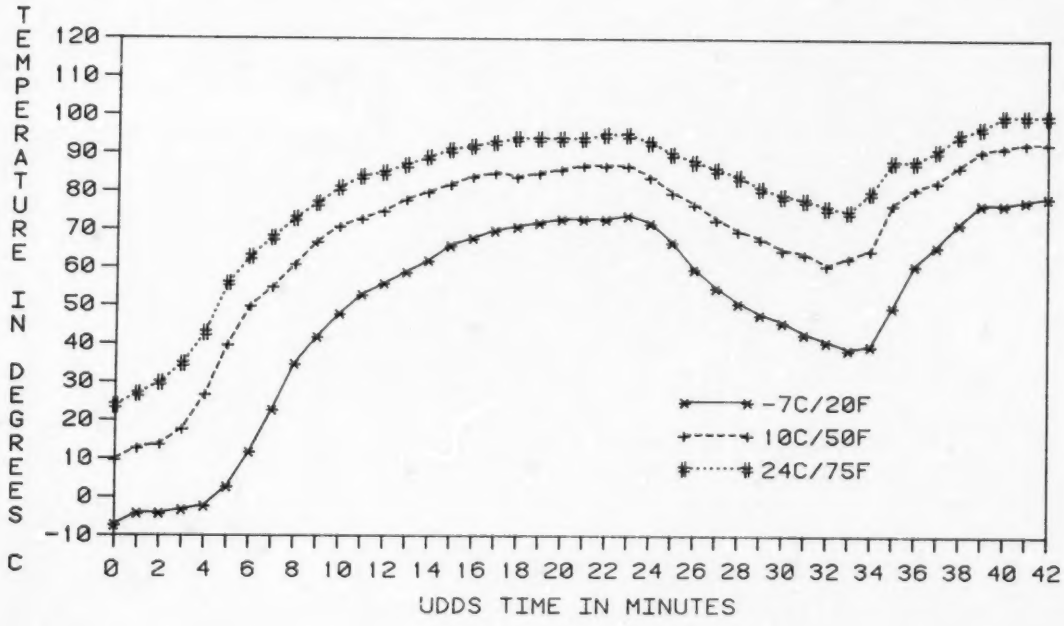

Figure 2b. Oil Sump Temperature vs. Time for HFET

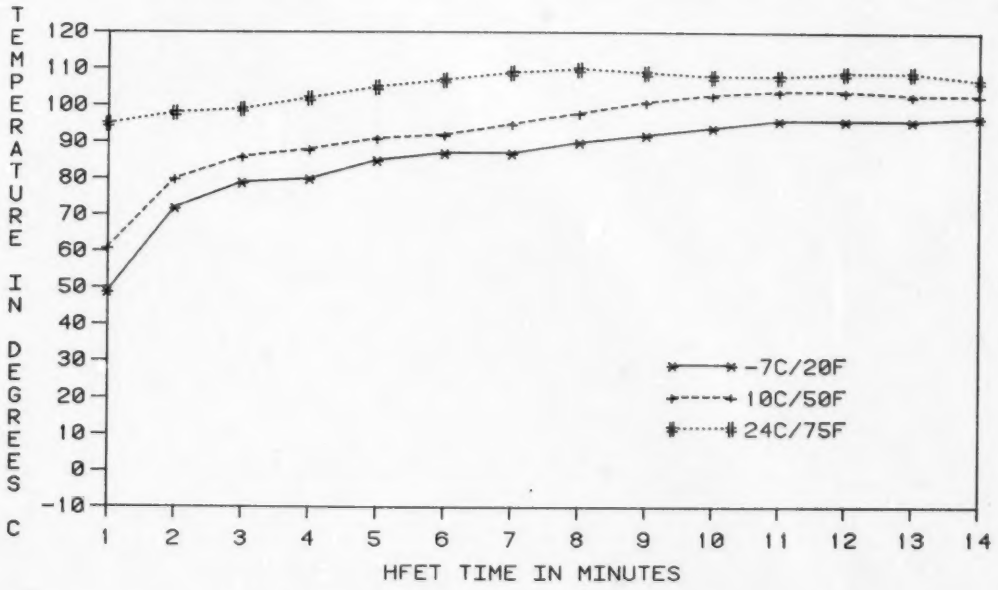

Figure 2c. Oil Sump Temperature vs. Time for NYCC

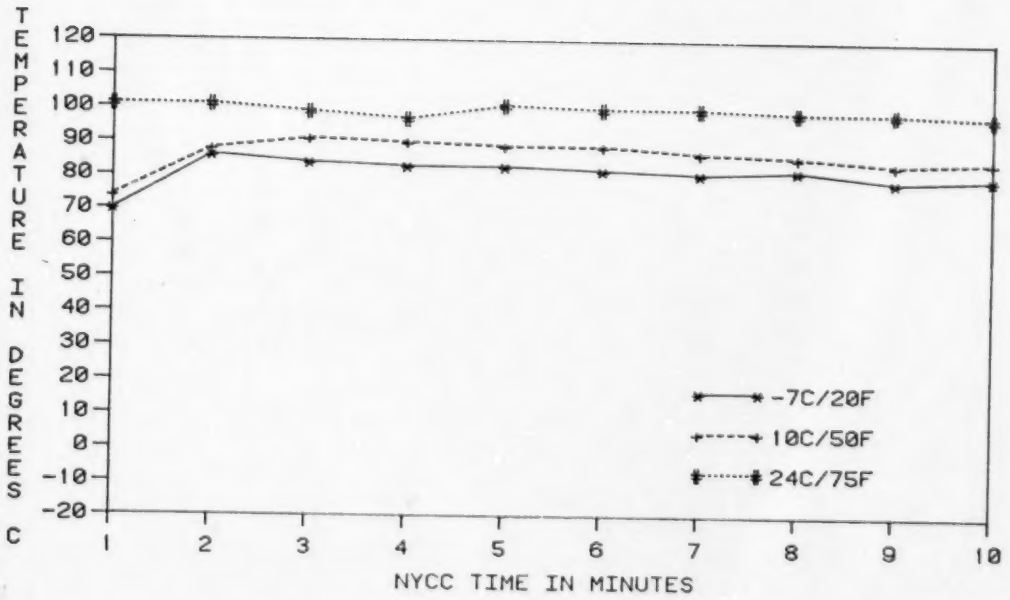

Figure 3

FTP EMISSIONS COMPARISON - CRC vs EPA

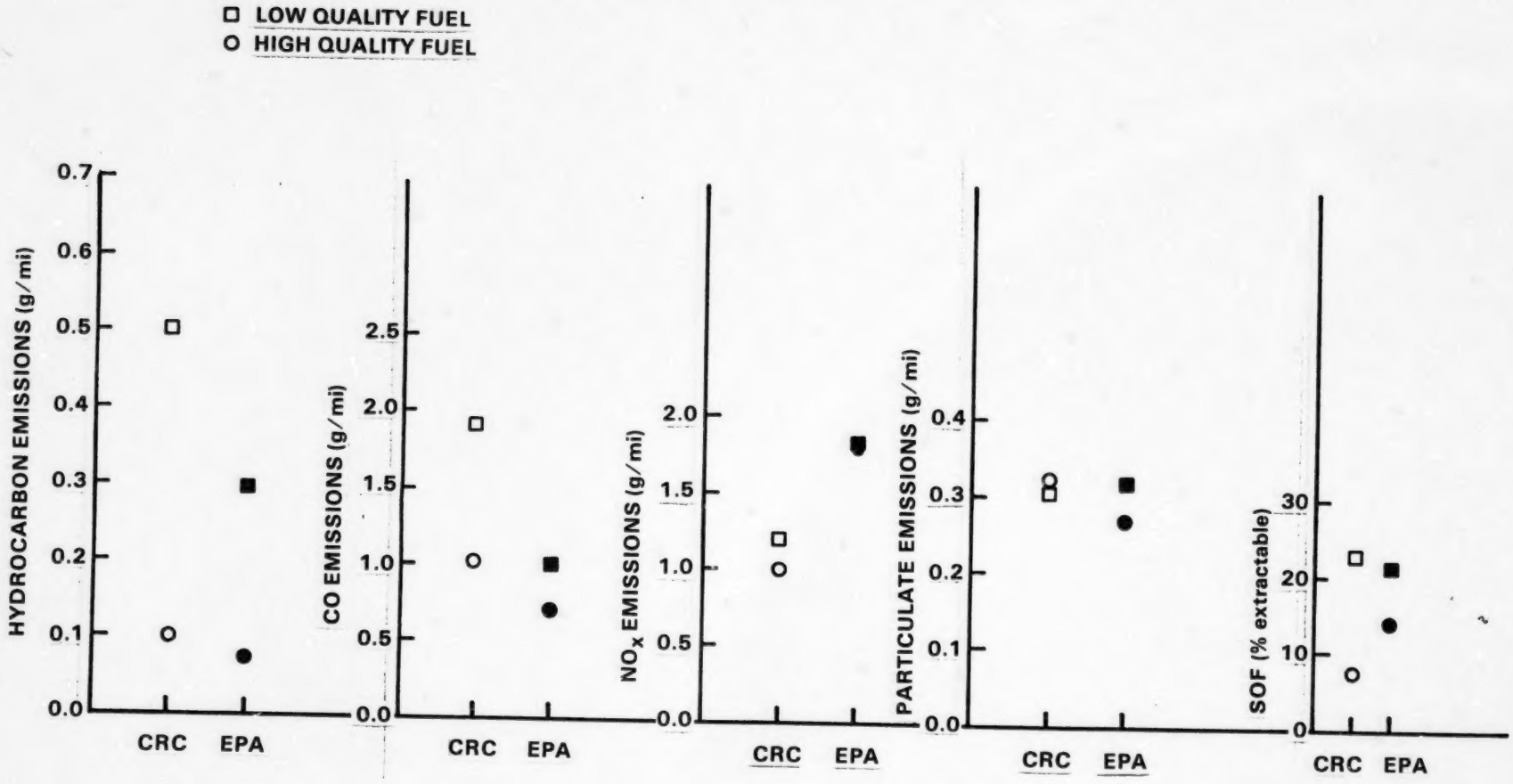

Figure 4a

FTP LOW QUALITY FUEL AT 75 50 AND 20

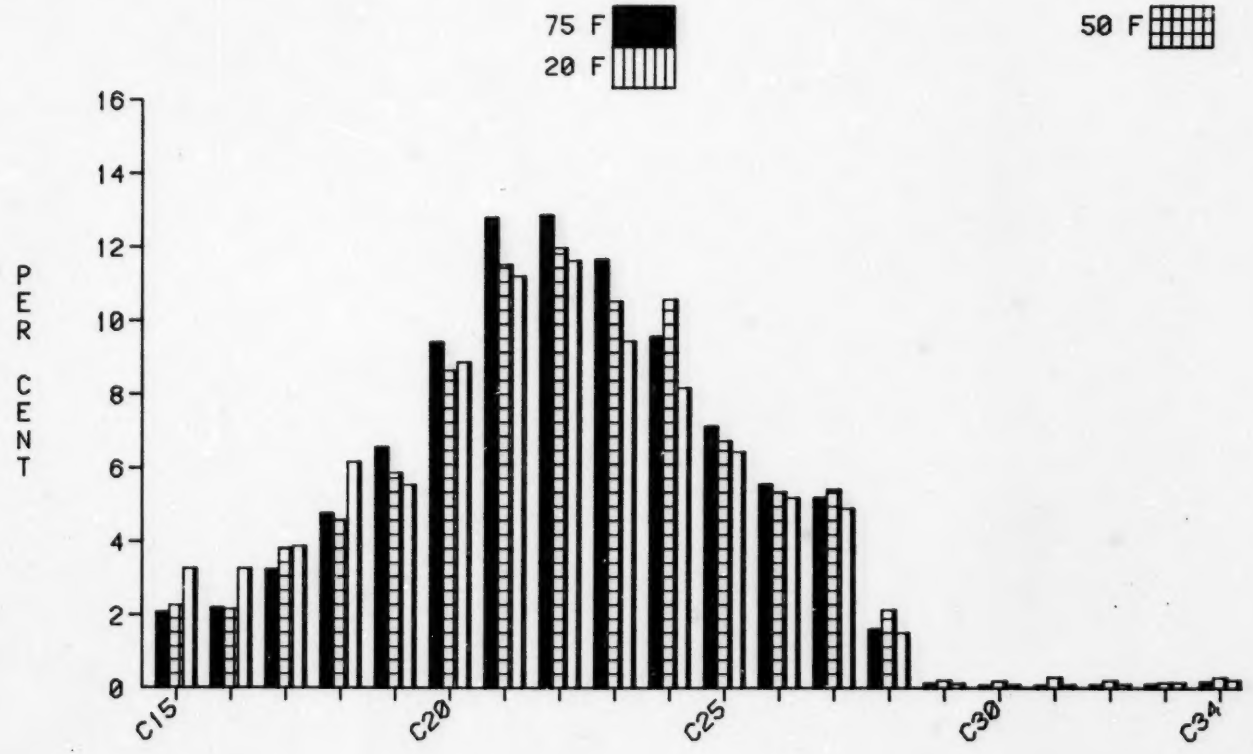

Figure 4b

FTP HIGH QUALITY FUEL AT 75 50 AND 20 F

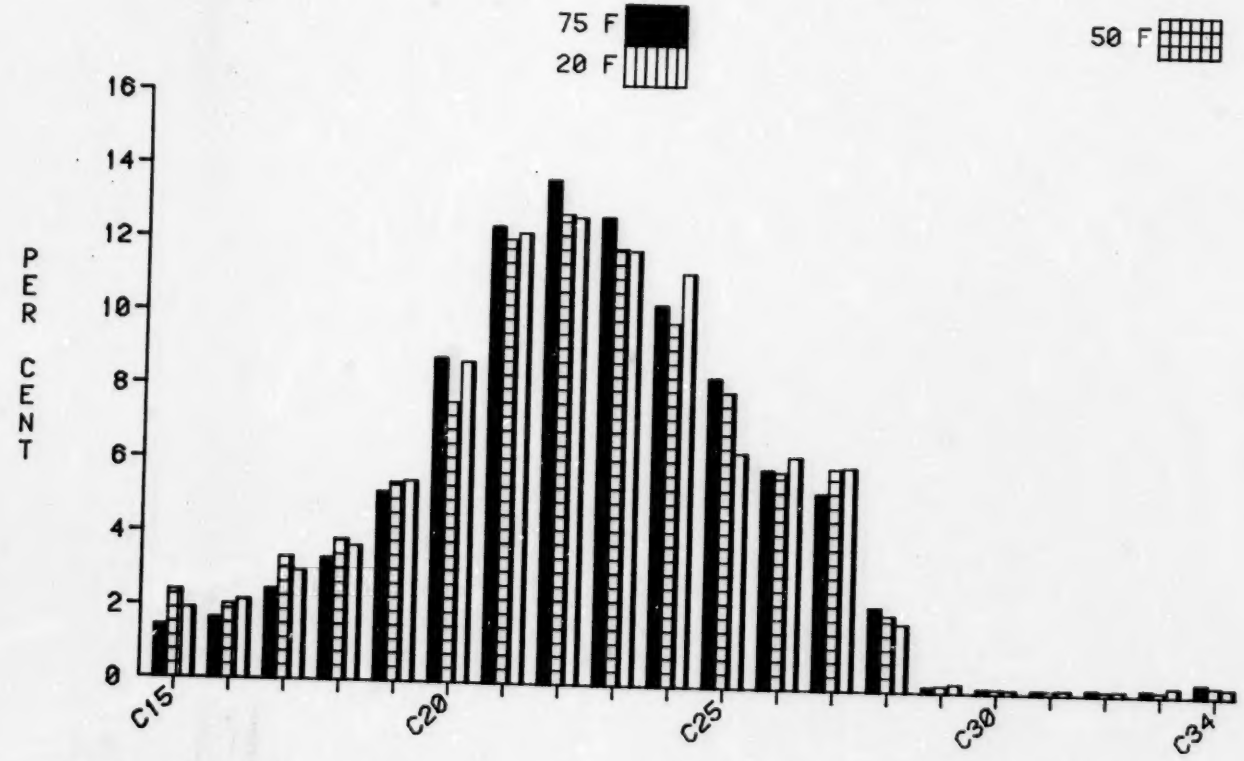

Figure 5. PERCENTAGE OF PARTICLES LESS THAN 2 MICRONS MMD.